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ABSTRACT

Two adaptive psychophysical procedures (tracking and "yes-no" staircase) for obtaining human visual contrast sensitivity functions (CSF) were evaluated. The procedures were chosen based on their proven validity and the desire to evaluate the practical effects of stimulus transients, since tracking procedures traditionally employ gradual stimulus onsets whereas staircase procedures traditionally employ rapid stimulus onsets. The criteria for deciding which procedure was preferable for the rapid testing of large groups of untrained observers were consistency in the form of the measured CSFs across days, the subjective ease of the procedure as judged by the observer, and the time required to obtain consistent results. Both procedures gave repeatable results across days; thus, the first CSF obtained from each subject could be taken as representative of the true CSF as determined by additional testing. However, the tracking procedure was judged easier to use by the researchers and required less time to perform. No interaction was found between any of these variables and the different stimulus onset parameters of the two procedures. (Author/TW)

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VISUAL CONTRAST SENSITIVITY FUNCTIONS OBTAINED FROM UNTRAINED OBSERVERS USING TRACKING AND STAIRCASE PROCEDURES

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Two adaptive psychophysical procedures (tracking and "yes-no" staircase) for obtaining human contrast sensitivity functions (CSFs) were evaluated. The procedures were chosen based on their proven validity and our desire to evaluate the practical effects of stimulus transients, since tracking procedures traditionally employ gradual stimulus onsets whereas staircase procedures traditionally employ rapid stimulus onsets. The criteria for deciding which procedure was preferable for the rapid testing of large groups of untrained observers were consistency in the form of the measured CSFs across days, the subjective ease of the procedure as judged by the observer, and the time required to obtain consistent results. Both procedures gave repeatable results across days; thus, the first CSF obtained from each subject could be taken as representative of the true CSF as determined by additional testing. However, the tracking procedure was judged easier to use by the present observers and required less time to perform. No interaction was found between any of these variables and the different stimulus onset parameters of the two procedures.

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SUMMARY

The contrast sensitivity function (CSF) is rapidly replacing tests of simple visual acuity as a criterion for establishing visual capability. It has been shown, for instance, that individuals with the same visual acuity may have drastically different CSFs, and that those differences may predict differences in performance on various visual tasks. The criteria for deciding among the techniques available for obtaining CSFs is usually some measure of efficiency or statistical variability. There have been relatively few attempts, however, at establishing practical criteria relevant to a given task. The present experiment is concerned with obtaining valid CSFs from untrained observers. Practical considerations dictated that the testing should last no longer than 30 minutes and that the procedures should be simple enough for untrained observers to perform. Toward this end, two standard psychophysical procedures were evaluated: a tracking method in which stimulus onset was gradual and a "yes-no" staircase method in which the stimulus was flashed for 0.25 second. Both procedures resulted in repeatable CSFs across days; but the tracking procedure could be performed in less time and was subjectively easier, as determined by the observers tested.

PREFACE

This research was performed in support of the Training Technology planning objective of the Research and Technology Plan at the Operations Training Division of the Air Force Human Resources Laboratory, Williams Air Force Base, Arizona. The general objective of this training research and development program is to identify and demonstrate cost-effective strategies and new training systems to develop and maintain combat effectiveness. The purpose of the present experiment was to elucidate the basic mechanisms underlying visually guided behavior in flight simulators.

The authors thank Dr. Thomas Longridge for administrative support and Mr. James Homoki for his assistance in software development and data collection. This research was supported by the Air Force Office of Scientific Research (Life Sciences Task 2313T3) and by Air Force Contract F33615-84-C-0066 (UDRI).

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VISUAL CONTRAST SENSITIVITY FUNCTIONS OBTAINED FROM UNTRAINED OBSERVERS USING TRACKING AND STAIRCASE PROCEDURES

I. INTRODUCTION

Human visual capability historically has been assessed by measures of visual acuity. These measures usually require an observer to identify high-contrast symbols of various sizes under standardized viewing conditions. It has become increasingly evident over the past ten years, however, that visual acuity measures alone are not adequate to specify an individual's ability to detect and recognize objects in real-life situations (cf. Ginsburg, 1986). A more complete assessment of visual capability is possible through measurement of the visual contrast sensitivity function (CSF). The CSF specifies the minimum amount of image contrast necessary for detection at various spatial frequencies. The highest spatial frequency that can be discerned at maximal contrast gives an estimate of visual acuity but represents only one point on the CSF.

The potential importance of the CSF in assessing visual function has motivated research designed to establish the most appropriate and most efficient means for obtaining these data. Several psychophysical techniques have been proposed for the rapid determination of the CSF using conventional stimulus displays.[1] For example, Sekuler and Tynan (1977) evaluated a tracking procedure in which both the spatial frequency and the contrast of a sine-wave grating were varied under computer control. The observer was required to depress a pushbutton as long as the grating remained visible. Sekuler and Tynan claimed that this technique is reliable, but they showed test-retest data for only one observer and for only the first two runs by that observer using their technique. Ginsburg and Cannon (1983) evaluated three standard techniques, including the tracking technique used by Sekuler and Tynan, and concluded that an increasing contrast method (equivalent to the ascending portion of the tracking procedure) was superior in that it resulted in more consistent CSFs over days, required the least time to administer, and was judged easiest to perform by their observers. It is not clear from Ginsburg and Cannon's data, however, whether the relatively low variability of the increasing contrast method is due to greater consistency over days, in the form of the CSF, or to greater consistency in overall sensitivity across observers. Further, all of the techniques evaluated by Ginsburg and Cannon employed gradual stimulus onsets; thus, any potential interactions between the form of the CSF and the transient characteristics of the stimulus cannot be evaluated from their data (see, however, Kelly & Savoie, 1973).

Several psychophysical procedures have recently been proposed for obtaining visual thresholds (Pentland, 1980; Watson & Pelli, 1983). These techniques are valuable in many research settings since they are

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[1] Methods using nonconventional displays have also been described (Dobson & Davison, 1980; Ginsburg, 1984; Wiley, Harding, Gribler, & Kirby, 1984) and should be considered when sufficient normative data are available.

statistically efficient and are able to assess sensitivity independently of the observers' response criterion. These attributes are less important in screening applications since the purpose is to distinguish abnormal sensitivity data within a normative population. The advantages of the newer techniques are also diminished in the screening situation by the fact that other variables that may affect the form of the sensitivity function are not usually controlled.

We have evaluated in the present experiment two well-validated psychophysical techniques (tracking and "yes-no" staircase), which by some criteria are actually preferable to the newer techniques (Emerson, 1986; Rose, Teller, & Rendleman, 1970). CSFs were obtained on four consecutive days. The criteria established to decide which psychophysical procedure was preferable for rapid testing of large groups of untrained observers were: repeatability for the same observer across days; the time required to obtain consistent results; and subjective ease of obtaining the CSF, as determined by the observers. A detailed analysis of variance was performed to determine which technique resulted in the more consistent determination of CSF. In addition, the staircase technique was implemented using discrete flashed stimuli, while the tracking technique used gradually varying contrasts. Thus, the effects of stimulus transients on the form of the CSF and on interactions between spatial frequency and either subjects or test day could be assessed.

II. METHOD

Observers and Apparatus. Eight male civilian employees of the Operations Training Division of the Air Force Human Resources Laboratory at Williams AFB, Arizona participated in the experiment. These observers were between 21 and 31 years of age; all observers were emmetropic and had no previous experience with contrast sensitivity testing. Staircase CSFs were obtained from one set of four observers (DRF, DJP, JCD, CKC), and tracking CSFs were obtained from another set of four observers (JKS, MRP, GAG, BKR). CSFs were obtained using an Optronix Series-200 Vision Tester consisting of an RCA Model TC1214 monitor, special-purpose video hardware, and an AIM-65 microprocessor. The tracking procedure used was that provided by the Optronix operating software, whereas the double-random staircase procedure was implemented by a BASIC program written specifically for this research.

Stimulus contrast (C) was defined as $C = (L_{max}-L_{min})/(L_{max}+L_{min})$ where L_{max} and L_{min} are the maximal and minimal luminances of the sine-wave stimuli. The mean luminance of the display was 150 cd/m^2, and it subtended 15 degrees (horizontal) x 20 degrees, at a viewing distance of 3 meters. The spatial frequencies tested, in random order, were 0.5, 1.0, 2.0, 4.0, 8.0, and 11.4 cycles per degree. For both procedures, the observers fixated a small black dot placed at the center of the display.

Procedure. Observers first adapted to the mean luminance of the stimulus display for five minutes. During this time, the nature of the task to be performed was described to them.

For the tracking procedure, contrast changed from zero to its maximum in 45 seconds, and 20 response reversals were obtained at each of the six spatial frequencies tested. A one-minute rest period was allowed between testing of successive spatial frequencies. Data were obtained in 15- to 20-minute sessions on four consecutive days.

For the staircase procedure, a double-random staircase (12 reversals on each) was used, with a step size of 0.12 log unit. One staircase was begun at a contrast well above threshold whereas the other was begun at a contrast well below threshold. Each stimulus was presented for 250 msec, and the interstimulus interval was eight seconds. A 250-msec warning tone was initiated one second before stimulus presentation. A one-minute rest period was allowed between testing of successive spatial frequencies. The staircase data were analyzed using methods suggested by Dixon and Massey (1957). Again, data were obtained for four consecutive days, with each session requiring 20 to 25 minutes.

Under both procedures, the observers were shown a high-contrast (C = 0.2) version at each spatial frequency, immediately preceding testing at that frequency. They were requested to respond as soon as they detected any spatial structure in the display.

Data Analysis. The data were analyzed using a split-plot analysis of variance with subjects nested under Method. The Subject factor was crossed with the Day and Frequency factors and was treated as a random factor which, along with its interactions, provided the four error terms for testing the Method, Day, and Frequency main effects and their interactions. The basic assumptions of the analysis were tested by examining residual plots which suggested that a logarithmic or square root transformation might be appropriate. Additional analyses were performed on the transformed data, and the results led to the same conclusions as those drawn from the analysis of the raw data. Therefore, only the results of the analysis performed on the raw data are presented.

III. RESULTS

The results of the analysis of variance are shown in Table 1. The only significant factors were the Frequency main effect and the Method x Frequency interaction.

Shown in Figure 1 are the four daily CSFs obtained by the tracking procedure for each of the four observers tested by this method. The data points represent the average of ten ascending and ten descending trials at each spatial frequency. For each observer, the CSF obtained on Day 1 is generally representative of the average data for the four days. This may be inferred from the fact that neither the Day main effect nor the Day x Frequency interaction was significant.

Shown in Figure 2 are the four daily CSFs obtained by the staircase procedure for each of the four observers tested by this method. The data points represent the average of approximately 24 response reversals obtained from the two staircases. As was the case for the tracking procedure, the CSF obtained on Day 1 was representative of the mean CSF for each observer.

Table 1. Summary of Split-Plot Analysis of Variance

Effect	df	MS	F	p
Method	1	3.655	2.66	.15
Subject	6	1.375	--	--
Day	3	0.063	1.49	.25
Method x Day	3	0.097	2.30	.11
Subject x Day	18	0.042	--	--
Frequency	5	3.825	43.5	.001*
Method x Frequency	5	0.444	5.06	.002*
Subject x Frequency	30	0.088	--	--
Day x Frequency	15	0.008	0.70	.78
Method x Day x Frequency	15	0.013	1.10	.37
Subject x Day x Frequency	90	0.012	--	--

* Statistically Significant.

The mean CSFs obtained for each of the four observers using the tracking procedure are shown in Figure 3. The means are tabulated in Table 2, along with their associated standard deviations. For three of the observers, the CSF peaked at 4 cycles/degree, whereas for the fourth observer, it peaked at 8 cycles/ degree. Although there were substantial individual differences at 1 and 2 cycles/degree, the curves were generally of the same shape and showed similar peak sensitivities.

The situation was quite different for the mean CSFs obtained for the four observers using the staircase procedure (Figure 4 and Table 3). In this case, peak sensitivities occurred at 2 cycles/degree for two observers and at 4 and 8 cycles/degree for the other two observers. Further, peak contrast sensitivity differed by as much as a factor of ten across observers, and the form of the CSFs differed noticeably.

Further differences between the CSFs obtained using the tracking and staircase procedures are evident from Figure 5, which shows the data of Figures 3 and 4 further averaged across observers. The tracking procedure resulted in a CSF that peaked at a higher spatial frequency than that obtained using the staircase procedure. Further, contrast sensitivity falls off more rapidly toward lower spatial frequencies for the tracking procedure than for the staircase procedure. The difference in the form of the CSFs obtained using the two procedures is evident also in the significant Method x Frequency interaction shown in Table 1.

Finally, Figure 6 shows the change in overall contrast sensitivity for each procedure as a function of testing day. As evidenced by this figure and by the nonsignificant Method main effect and Method x Day interaction, neither technique showed any statistically significant change in measured sensitivity across testing sessions; there was essentially no difference between the two methods measured across days.

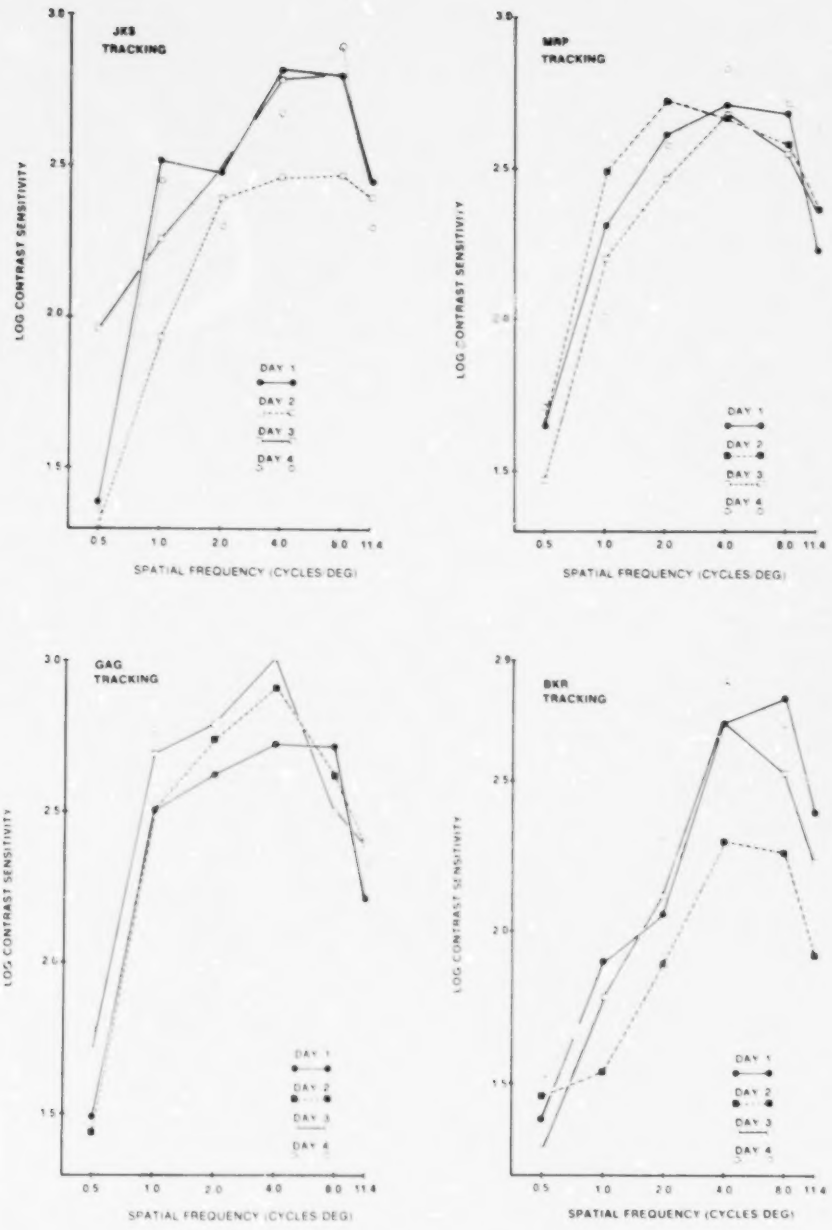

Figure 1. The CSFs Obtained on Four Consecutive Days From Each of the Four Observers Tested Using the Tracking Procedure.

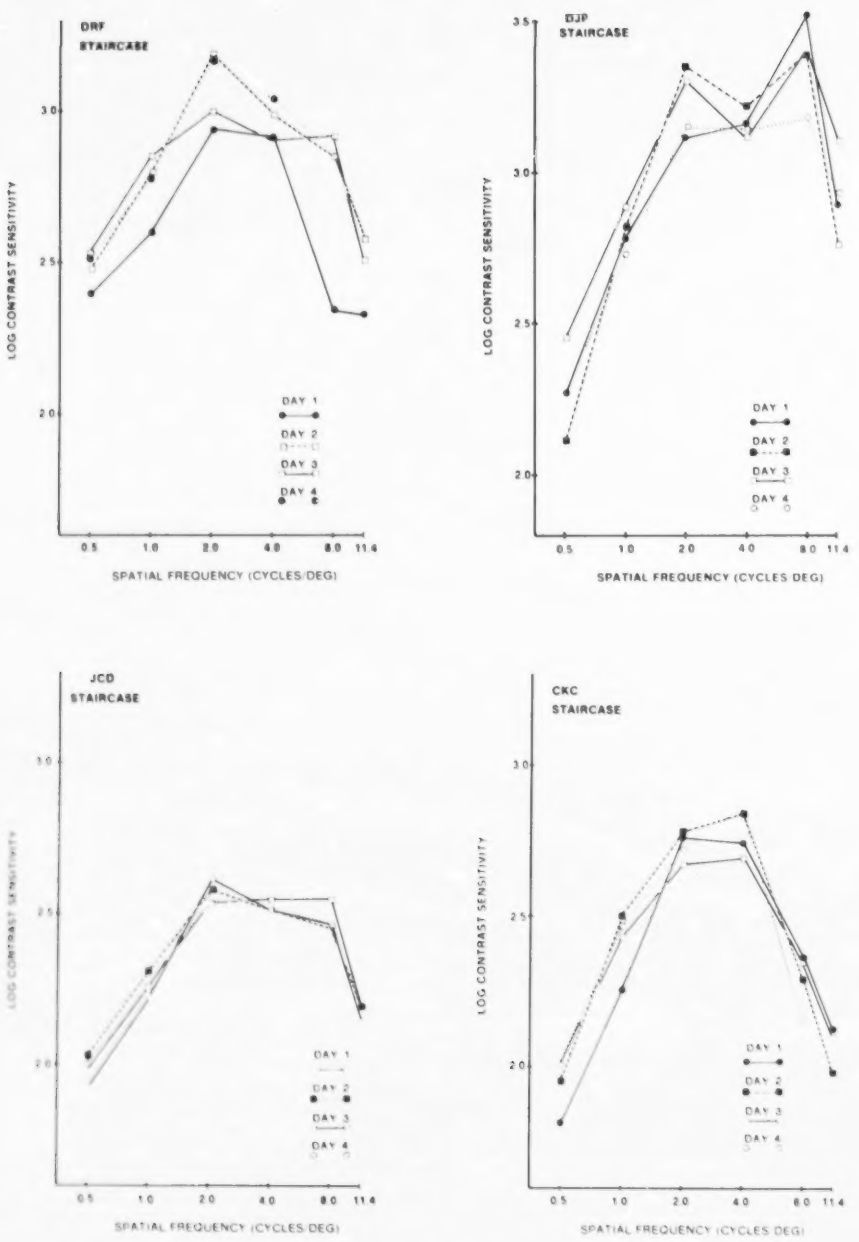

Figure 2. The CSFs Obtained on Four Consecutive Days From Each of the Four Observers Tested Using the Staircase Procedure.

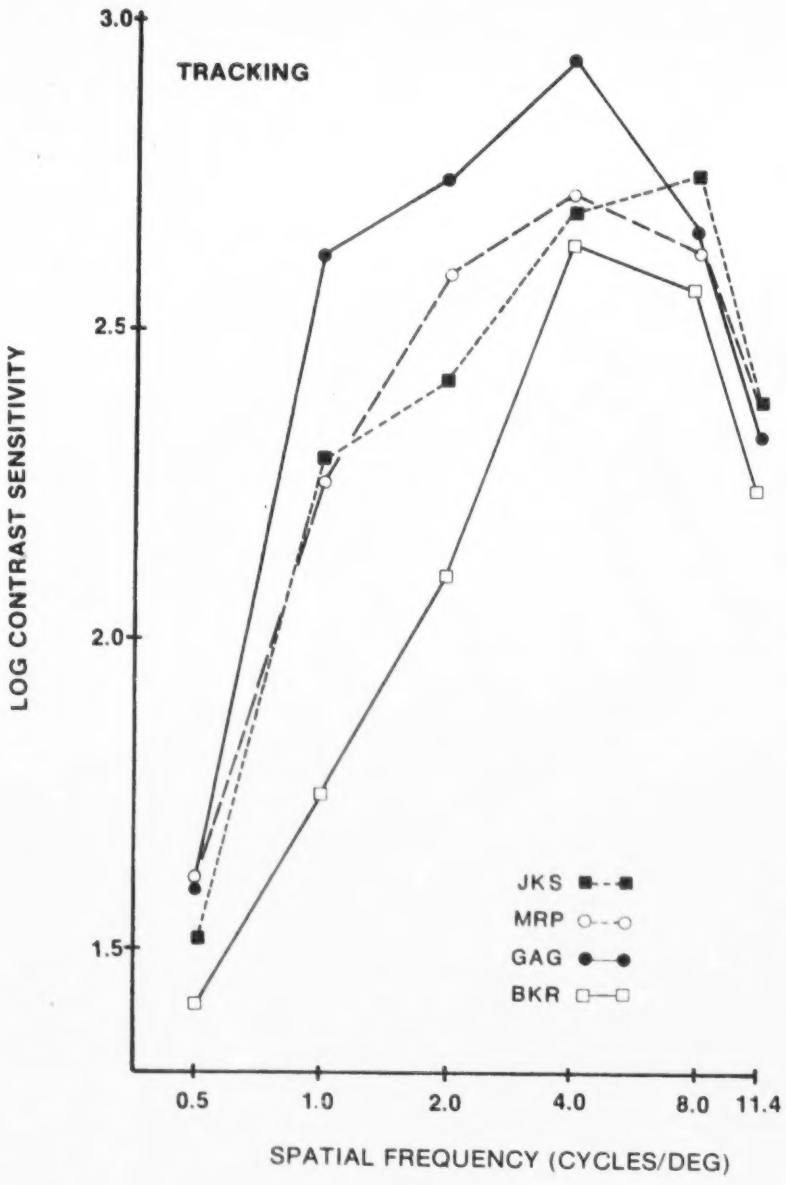

Figure 3. The CSFs Obtained Using the Tracking Procedure and Averaged Over the Four Sessions for Each Observer.

Table 2. Tracking Procedure: Log Contrast Sensitivity and Summary Statistics Corresponding to the CSFs of Figures 1, 3, and 5. Threshold contrast may be obtained by taking the logarithm (base 10) of the negatives of each table entry.

	Day		0.5	1.0	2.0	4.0	8.0	11.4
JKS	1		1.392	2.521	2.482	2.823	2.807	2.451
	2		1.309	1.931	2.388	2.462	2.468	2.401
	3		1.957	2.261	2.488	2.793	2.808	2.440
	4		1.355	2.445	2.315	2.676	2.914	2.311
		$\bar{x}$	1.503	2.290	2.418	2.689	2.749	2.401
		sd	0.3044	0.2627	0.0827	0.1638	0.1941	0.0636
MRP	1		1.652	2.313	2.614	2.710	2.682	2.231
	2		1.652	2.488	2.721	2.661	2.581	2.361
	3		1.472	2.214	2.469	2.681	2.552	2.347
	4		1.706	2.014	2.569	2.826	2.720	2.632
		$\bar{x}$	1.621	2.257	2.593	2.720	2.634	2.393
		sd	0.1022	0.1978	0.1045	0.0738	0.0801	0.1698
BKR	1		1.394	1.898	2.058	2.690	2.778	2.398
	2		1.463	1.538	1.898	2.312	2.266	1.931
	3		1.283	1.778	2.119	2.700	2.529	2.225
	4		1.508	1.791	2.323	2.841	2.695	2.391
		$\bar{x}$	1.412	1.751	2.100	2.636	2.567	2.236
		sd	0.0979	0.1520	0.1757	0.2266	0.2258	0.2186
GAG	1		1.494	2.504	2.620	2.772	2.714	2.208
	2		1.438	2.509	2.738	2.910	2.619	2.391
	3		1.708	2.689	2.794	3.007	2.501	2.388
	4		1.761	2.773	2.824	3.057	2.827	2.328
		$\bar{x}$	1.600	2.619	2.744	2.937	2.665	2.329
		sd	0.1582	0.1341	0.0900	0.1255	0.1386	0.0856
Grand Mean			1.534	2.229	2.464	2.746	2.654	2.340

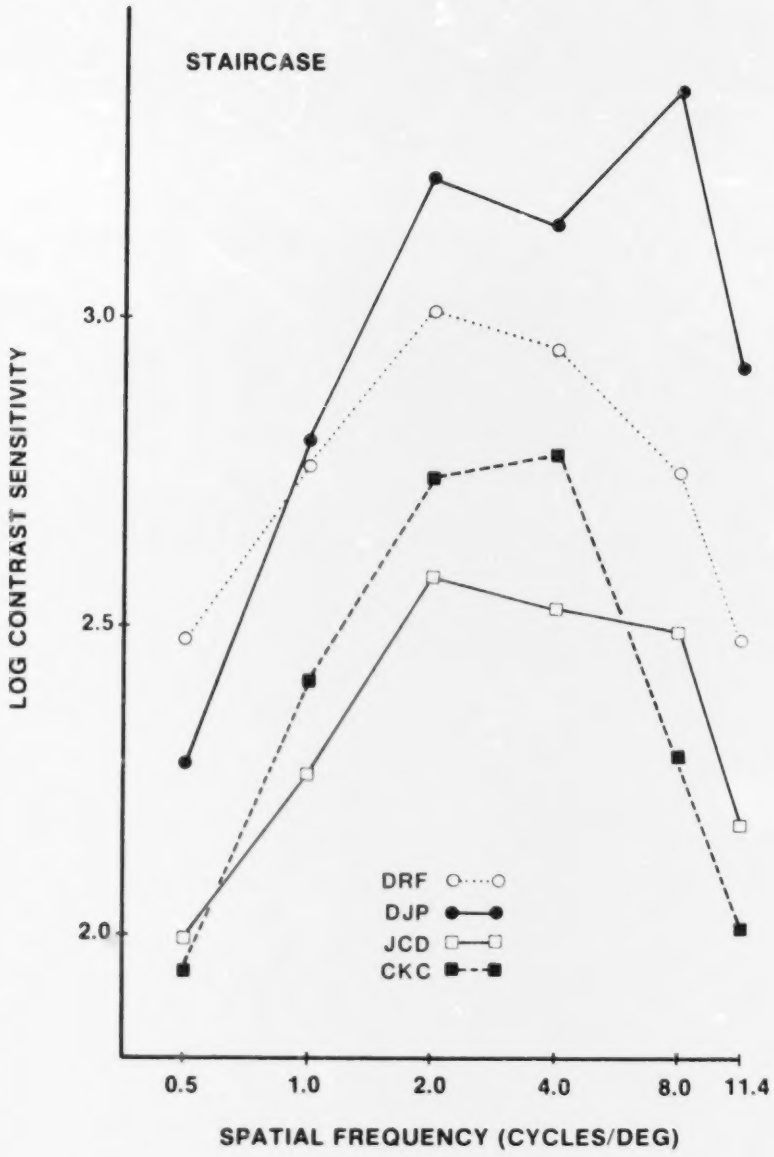

Figure 4. The CSFs Obtained Using the Staircase Procedure and Averaged Over the Four Sessions for Each Observer.

Table 3. Staircase Procedure: Log Contrast Sensitivity and Summary Statistics Corresponding to the CSFs of Figures 2, 4, and 5. Threshold contrast may be obtained by taking the logarithm (base 10) of the negatives of each table entry.

	Day		0.5	1.0	2.0	4.0	8.0	11.4
DRF	1		2.397	2.606	2.937	2.909	2.344	2.334
	2		2.476	2.796	3.193	2.952	2.854	2.575
	3		2.530	2.848	3.020	2.897	2.921	2.513
	4		2.509	2.783	3.166	3.038	2.864	2.511
		$\bar{x}$	2.478	2.758	3.079	2.949	2.746	2.483
		sd	0.0584	0.1053	0.1214	0.0639	0.2695	0.1038
DJP	1		2.274	2.784	3.117	3.157	3.515	2.887
	2		2.114	2.822	3.353	3.212	3.394	2.763
	3		2.454	2.881	3.305	3.111	3.386	3.097
	4		2.269	2.730	3.146	3.137	3.179	2.932
		$\bar{x}$	2.278	2.804	3.230	3.154	3.369	2.920
		sd	0.1390	0.0636	0.1163	0.0429	0.1394	0.1381
CKC	1		1.813	2.258	2.759	2.736	2.361	2.116
	2		1.951	2.494	2.783	2.838	2.287	1.976
	3		2.010	2.430	2.665	2.690	2.356	2.095
	4		2.001	2.469	2.736	2.855	2.160	1.980
		$\bar{x}$	1.944	2.413	2.736	2.780	2.291	2.042
		sd	0.0909	0.1065	0.0624	0.0796	0.0936	0.0741
JCD	1		1.932	2.234	2.622	2.521	2.468	2.152
	2		2.028	2.313	2.583	2.522	2.458	2.184
	3		1.995	2.259	2.542	2.550	2.566	2.190
	4		2.025	2.226	2.579	2.531	2.473	2.175
		$\bar{x}$	1.995	2.258	2.582	2.531	2.491	2.175
		sd	0.0546	0.0393	0.0327	0.0165	0.0502	0.0204
Grand Mean			2.174	2.558	2.907	2.854	2.724	2.405

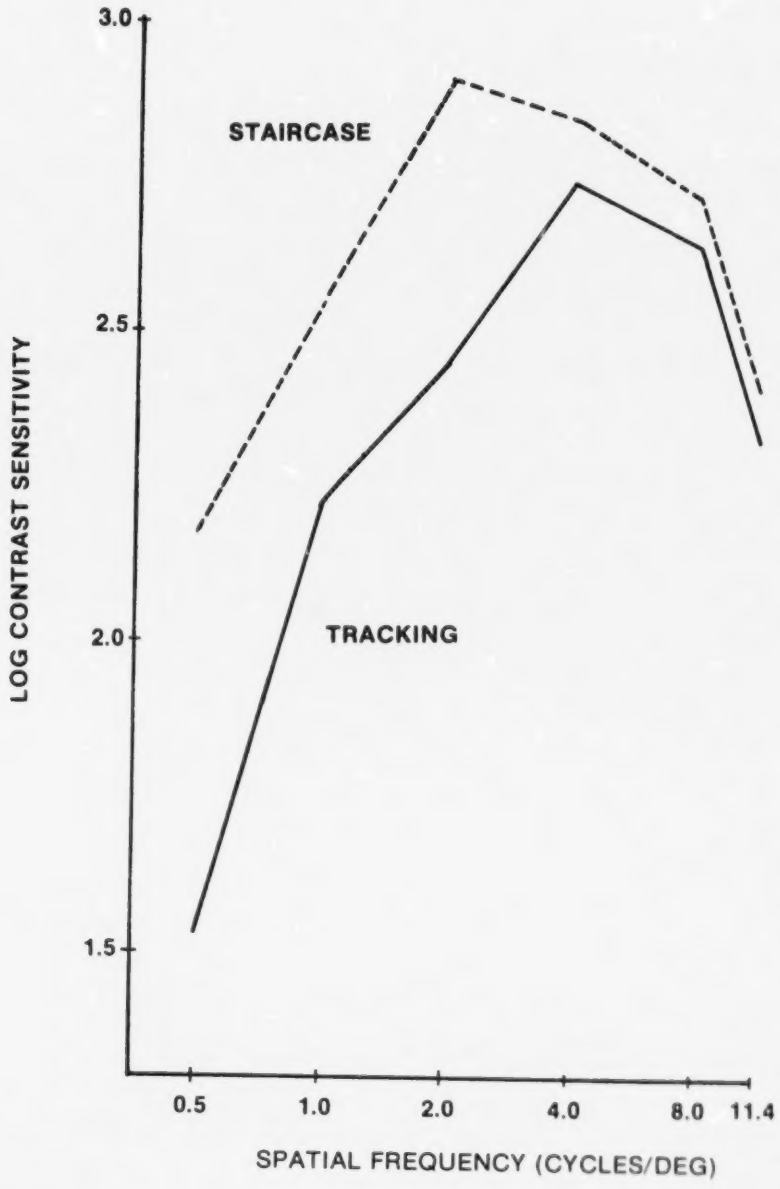

Figure 5. Mean CSFs for the Staircase and Tracking Procedures. These data are averages taken over all four observers tested under each condition.

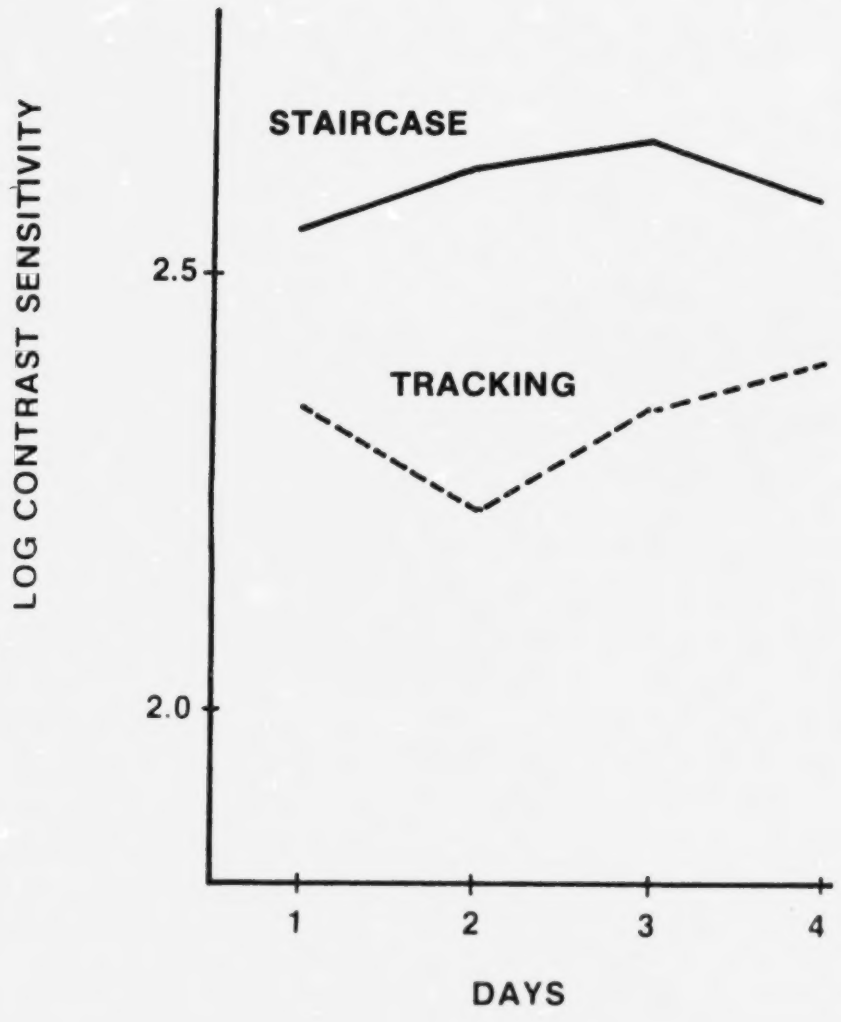

Figure 6. The Mean Contrast Sensitivity, for All Four Observers Tested by the Staircase and Tracking Procedures, as a Function of Testing Day.

IV. DISCUSSION

Any psychophysical procedure used for screening purposes must give repeatable results across days, both in the form of the CSF and in overall sensitivity. Both the tracking and staircase procedures evaluated here proved adequate by these criteria. The nonsignificant Day x Frequency interaction indicates that the form of the CSFs averaged over the two methods was consistent across the four days of testing. The nonsignificant Method x Day x Frequency interaction further suggests that the form of the CSFs obtained with each method was also consistent across days (compare Figures 1 and 2). There was no detectable difference in the overall contrast sensitivity obtained by the two methods given the nonsignificant Method main effect, and no detectable difference in changes in sensitivity across days for the two methods was observed (see Figure 6) given the nonsignificant Method x Day interaction. The tracking procedure appeared to give more consistent results across observers (compare Figures 3 and 4), but the practical significance of this result is difficult to assess based on the data from four subjects. The only remaining criteria by which the present tracking and staircase procedures can be evaluated are the time required to obtain CSFs and the subjective ease with which CSFs were obtained. The tracking procedure must be considered superior according to these criteria.

There is evidence from the psychophysical literature for a functional distinction between so-called transient and sustained channels in the visual system (Kulikowski & Tolhurst, 1973). Transient channels have been shown to be selective for large, low-spatial-frequency stimuli and intermittent stimulation (such as high rates of flicker, for instance). Sustained channels show selectivity for small, high-spatial-frequency stimuli presented for long durations or at low flicker rates. The data of Figure 5 are consistent with the above-described dichotomy between transient and sustained channels (see, however, Arend (1976a) for another explanation). The rapid stimulus onset used in the present staircase procedure results in transient stimulation, and may be expected to result in greater stimulation of low-spatial-frequency channels than would the tracking procedure. Figure 5 indicates that this was indeed the case. The CSFs obtained by the staircase and tracking procedures nevertheless both showed a pronounced reduction in sensitivity at the lower spatial frequencies. This qualitative similarity in the form of the two functions is evidence of the robustness of these data in the face of significant differences in the transient characteristics of the stimuli used to obtain them. Of course, the possible interaction of stimulus onset with other display parameters must also be considered.

Although it is clearly important to consider possible explanations for differences in the form of CSFs obtained by different procedures, only limited conclusions concerning underlying visual mechanisms can be drawn from the data of the present experiment. These data were obtained using psychophysical procedures which allowed a rapid determination of the CSF but which did not control for factors such as stimulus duration (Arend, 1976b), surround illuminance (Estevez & Cavonius, 1976), number of cycles displayed (McCann & Hall, 1980), and stimulus onset parameters (Tulunay-Keesey & Bennis, 1979), which may also affect the form of the CSF. This fact is obvious from Figure 5, which indicates that both the spatial frequency corresponding to peak sensitivity and the sensitivity at lower spatial frequencies depend on the psychophysical method chosen. Thus, unless extensive controlled experiments are performed, valid comparisons can be made only among observers tested using the same psychophysical procedure.

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